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A SURVEY OF PIPE CORROSION AT NAVAL ACTIVITIES

BY

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Type C

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ABSTRACT

To determine the effectiveness of methods used in the field to protect pipeline systems from corrosion within a group of government activities, engineers from the U. S. Naval Civil Engineering Laboratory made on-site investigations of piping distribution systems in a total of twenty-three Naval activities located in various places of the Pacific coast, Atlantic coast, gulf coast, Hawaii and inland California. The data collected from the sites were more commonly from service pipelines such as steam, hot water, potable water, sea water, sewage, air, gas and oil One hundred and six pipe installations were investigated. Information as to site, soil characteristics, type of coating or covering, date of installation, length of pipe involved, and reports on the success or failure of the systems are recorded in tabular form and entered in Appendixes A and B. The most serious failures reported are in underground hot pipeline systems where, in most cases, the lines are installed below the water table.

INTRODUCTION

The purpose of this study was to assemble information from Government activities at different locations, to compare and evaluate the data, and to obtain some realistic value of the pipe corrosion problems prevailing in Government activities. The findings of the study will be used to formulate procedures for a series of field tests to determine materials which can be most economically substituted for presently specified systems. Information obtained contains case histories where serious pipe corrosion has occurred, and what field measures were used to check accelerated corrosion. Locations where corrosion control was difficult and maintenance was high, suggest possible sites for more intensive investigations. During the survey, special attention was given to the use of noncorrosive materials, to heat distribution piping, and to cathodic protection applications, which in many cases were reported to be quite effective.

Information as to the characteristics of the soil, the sites of pipeline failure, and the observations of operating personnel, were recorded for possible future fields of exploration.

Over the past ten years some activities have reported on literally hundreds of individual pipe leaks, but the pipe failures recorded in this report have been limited to those of major significance. Case histories of many successful installations are also included.

Costs for repairs of pipe failures were requested at all sites, but where the work was performed by station personnel, no useable records of costs were found to be available. Station maintenance costs for all types of repairs are charged to one account making it impossible to determine the amounts actually spent on corrosion repairs. This is one reason why other investigating agencies using government accounting records have erroneously predicted excessive corrosion maintenance costs.

Information for this study was gathered by NCEL engineers who visited the SOWESTDIVDOCKS, NORWESTDIVDOCKS, 12ND, 14ND, 8ND, and SOEASTDIVDOCKS. Within these divisions and districts twenty-three activities were visited and information was obtained on several others. The data on pipe failures and the use of plastics pipe came chiefly from personnel in the public works offices, while data on soils came chiefly from corrosion reports written by consulting engineers. Specimens of pipe failures were

frequently available for examination. Trenches and manholes were inspected in problem areas and occasionally a replacement or pipeline repair was observed in progress.

NCEL engineers were impressed by the efforts of public works personnel in substantially reducing corrosion costs through the use of noncorrosive materials and cathodic protection.

ENVIRONMENT OF PIPING SYSTEMS

Soils

Data shown in Appendix A, Table I, were reproduced from reports made by consulting engineers who conducted corrosion surveys at the activities visited. Activities along the coast generally have a lot of earth fill which, if not corrosive itself, often covers a corrosive marshland. Inland activities are frequently located in areas unsuited for agriculture, such as old lake beds where the soil is highly alkaline. Consequently, the presence of corrosive soil at Naval activities is to be expected and should be considered in the design of buried structures so that the optimum in corrosion protection in the initial construction of permanent structures may be the most economical investment.

Resistivity tests give a good indication of the degree of corrosivity of the soil; however, the results should be considered in conjunction with other factors. The following quotation is taken from Reference 1:

> "Low resistivity soils are corrosive. Medium and high resistivity soils were once thought of as not being particularly corrosive. However, much corrosion has been found in high resistivity soil areas, consequently, difference in resistivity of soils in contact with different parts of a structure is a more accurate indication with medium and high resistivity soils. Alkaline soils are usually very low in resistivity because of large amounts of soluble salts in the soil, and are considered as being very corrosive."

Three thousand ohm-per-cubic centimeter (called ohm-cm) is classified as low and therefore corrosive, but a pipe passing through soils of different resistivities may be in a corrosive area even though the resistivities are as high as 30,000 ohm-cm. It is for this reason that the following statement taken from Type Specifications TS-P28c 1962 IV does not adequately cover the situation:

> "If readings indicate a soil resistivity or less than 2,000 ohm per cubic centimeter, then a detailed investigation for cathodic protection shall be undertaken."

Atmospheric Conditions

Most systems studied were located underground; consequently, atmospheric conditions were not as important as soil conditions. However, for those activities which have pipes under piers the outdoor environment is quite important. Piers vary in construction and location but generally speaking the pipes under piers are subject to high humidity, salt spray and sometimes splash. In addition to this, pipe coatings are frequently damaged by floating debris which leads to accelerated corrosion of the exposed metal. In Charleston the pipes are sometimes completely under water which aggravates the problem. In Key West, where the temperature and humidity are consistently high, atmospheric conditions are extremely corrosive which not only causes deterioration of pipes under piers but also many components of mechanical systems such as cooling towers and storage tanks.

PIPING SYSTEMS

Steam Pipes

The four major categories of underground steam pipes are (1) prefabricated conduit, (2) concrete trenches or tunnels, (3) tile conduit and (4) insulating hydrocarbons. Categories (1) and (2) are most important, category (3) is used only sparingly, and category (4) no longer qualifies for installation at Naval activities under Type Specifications TS-P28e.

Prefabricated conduit systems consist of single or multiple insulated piping completely enclosed in a waterproof conduit. A continuous annular space is maintained between the outer surface of the pipe insulation and the inner surface of the conduit. The outer casings are usually steel, cast iron or asbestos-cement. When the prefabricated sections are put in place, the pipes are welded together and the casing ends are welded, bolted or bonded. A protective coating is applied to the casing joints which is particularly important for welds where electro-chemical cells may form. To qualify as a class "A" system it must be capable of withstanding 20 psig air pressure which permits the installation of the system in any site where the water table is expected to be above the bottom of the conduit at any time.

The prefabricated systems encountered in this study were all of steel conduit with the exception of case S-III (see Appendix B, Table II) where cast iron was tried as a replacement. The failures to these systems constitute the most serious corrosion problems reported during this study.

The two principal causes of failure were (1) soil corrosion which perforated the casing, thus opening the way for flooding, and (2) internal corrosion of the condensate main which resulted in internal corrosion of

the casing. Some activities, which have very corrosive soil, have cathodic protection on all underground steel pipes for gas and fuel oil but none on their prefabricated conduit system. In view of the fact that the cost per foot of conduit containing a 2-1/2-inch steam main is approximately six and one-half times greater than an equivalent sized gas main, it seems rather incongruous that it should be left unprotected. The Federal Construction Council, made similar observations in their field investigation of underground heat distribution systems, which are noted in Reference 2.

If a conduit is carrying a steam main only, the greatest danger is from soil corrosion to the conduit rather than failure of the steam pipe which resists corrosion because of its high temperature. Where failure of the conduit occurs, the insulation becomes wet, resulting in unnecessary steam demands because of heat loss to the soil. Case S-VI is an example of conduit failure and undetermined heat loss. If the conduit is carrying both steam and condensate the possibility of internal corrosion in the return line is an additional hazard. The occurrence of such leaks may go undetected for some time causing interior corrosion of the conduit and exterior corrosion of the piping. All failures discussed above are difficult to locate; consequently, their discovery and repair are usually quite costly.

In prefabricated conduit design, the main countermeasure being taken is to increase the thickness of the metal casing and the quality of the protective coating. Unfortunately, these measures are no guarantee against poor workmanship during installation. As an additional protective measure, cathodic protection should be given adequate consideration. An alternate approach would be the development of noncorrosive conduits which could be made compatible with the temperatures and expansions associated with the steam pipe. Asbestos-cement looks promising[3] and other materials such as PVC and epoxy-glass should be investigated for this application. Cellular glass might be used as a protective insulation requiring no conduit.

Trenches are known as class "B" systems, which are installed on sites where water or the water table is not expected to be above the bottom of the conduit at any time. Where the installations have truly been on class "B" sites, the trenches proved to be highly successful. At a number of activities along the gulf coast and eastern seaboard, where the water table is high and drainage poor, as in cases S-XII and S-XIX, the trenches are frequently flooded resulting in insulation damage, loss of heat and external corrosion of the condensate pipes. The initial cost of trenches is higher than other enclosures but the life expectancy is almost unlimited, which has made them a good investment at many activities. The only failures to trenches themselves were reported in cases S-X and S-XVII where the reinforcing bars corroded.

Tile conduit systems like trenches are known as class "B" systems. Cases S-XX and S-XXI are examples of successful installations, but they are relatively expensive and not as convenient for repairs as trenches. Furthermore, trenches are more capable of carrying away water due to seepage without wetting the pipe insulation.

Insulating hydrocarbons were widely used after World War II as an inexpensive method of providing both insulation and corrosion protection with a single material. The "hydrocarbon" is a granular asphaltic material which under the proper conditions of pouring and "curing" forms three zones - consolidated, sintered and loose. The consolidated zone, next to the pipe, provides the corrosion protection while the other two layers provide insulation. Unfortunately, the three zones are not always properly maintained and the pipe becomes exposed to the soil due to cracking or slumping of the hydrocarbon. Cases S-XXII and S-XXIII are examples of successful installations, but many failures have been reported in the past with the result that this method is no longer permitted under BUDOCKS instructions.

Condensate Pipes

Underground condensate pipes are installed in the same manner as steam pipes. Consequently, the previous remarks concerning conduits, trenches and insulating hydrocarbons also apply to condensate installations. Additional comments will be made on both internal and external corrosion of the pipes which do not generally apply to steam pipes.

The most serious problem is internal corrosion. The Bureau of Mines has done some excellent work in this field and maintenance engineers should have ready access to their reports. Internal corrosion is due mainly to the presence of carbon dioxide. Berk and Hopps in a Bureau of Mines report[4] state that "if the carbon dioxide content of the steam cannot be kept from reaching a corrosion producing level, the only other positive method of protecting the conventional steel or wrought iron return system is neutralization of the carbonic acid in the system." Neutralizing amines are used at most of the activities included in this study. However, the treatment is quite expensive where the feedwater make-up rate is high. It is debatable as to whether it is economically better to use the amines or to replace the corroded pipe with a more expensive noncorrosive pipe. Case C-II (Appendix B, Table III) gives some cost figures which illustrate the problem for one activity with a high make-up rate, and since many Naval activities have a high make-up rate, the economical aspects of amine treatment should be closely watched.

In a number of instances, such as cases C-VI and C-X, there is evidence that ferrous condensate pipes are so expensive to maintain and replace that it is cheaper to eliminate the return pipes, dump the condensate and use 100 per cent make-up. These cases apply where water can be economically wasted.

The worst failures were found where external corrosion occurred in combination with internal corrosion as in cases C-X and C-XI.

The findings indicate that wider applications should be made of the use of epoxy-glass, copper or possibly stainless steel pipe which is sometimes used in commercial district heating systems.[5] Under the section on Plastics Pipes, Case P-II (Appendix B, Table IX) gives comments on a rigorous test of a pressurized condensate main using cast epoxy-glass. Other information on characteristics and comparative costs of different materials can be found in Reference 6.

Hot Water Pipes

Hot water systems when located underground are installed in the same way as steam systems and their problems are somewhat parallel. Hot water heating systems have very little internal corrosion and the high temperature pipes are able to resist external corrosion. Domestic water systems having fresh water continually introduced into the pipes frequently fail from internal corrosion.

The trenches in case H-I and case H-III (Appendix B, Table IV) have served their purpose well, but in case H-II the trench was placed below the water table resulting in damage to 25 per cent of the insulation and a heat loss costing $26,000 per year.

The prefabricated steel conduit in case H-IV, with an exterior coating as its only protection, failed in three years, whereas, the steel jacket in case H-VI under cathodic protection has been intact for twenty years. This was one of the rare cases where cathodic protection was found on hot pipe conduit, and the results suggest that it should be used more often.

Case H-VII illustrates the drastic results that can occur when an internal leak goes undetected inside a conduit. Every effort should be made to avoid this costly problem, either by placing the pipes which are subject to internal corrosion in a separate conduit or using noncorrosive pipes.

The use of insulating concrete was encountered only once and the unfortunate results outlined in case H-IX are in accordance with Reference 7, which reported on numerous cases and found the method to be quite unsatisfactory.

For domestic hot water, copper pipes were preferred and no leaks were reported; however, copper is not immune from attack by CO_2. Some typical case histories with preventive measures are given in References 8 and 9.

Cold Water Pipes

The most notable water pipe failures occurred to large copper fittings installed in asbestos-cement systems; to ferrous lines as a result of soil corrosion; and to pipes under piers. The failure of copper tees in asbestos-cement systems is rather unique and has proved costly and troublesome in a number of cases. It poses no special problem, however, since cast iron fittings have been very successful for this requirement. Soil corrosion has been extensive and coatings are not a foolproof solution to the problem since there is ample evidence that coatings are damaged during installation leaving the exposed pipe subject to corrosion. The best answer to this problem is the use of cathodic protection for existing systems and noncorrosive materials for new systems. In a number of instances dissimilar metals were the cause of failure. But, in case W-XIII (Appendix B, Table V), at Mare Island, where cast iron bolts were anodic to the cast iron pipe, the failure would not likely be anticipated by the average design engineer. This emphasizes the importance of having competent corrosion engineers approve new installations. Pipes under piers are subject to a salt spray environment and to liquids and other matter dripping from the deck. Frequently, the pipes must resist wave action and floating debris which means that the pipes must be strong as well as corrosion resistant. Because of their location they are expensive to repair or replace; consequently, if space is available, they are usually relocated on deck. Case W-XVII gives an example of the successful use of asbestos-cement pipe which has been avoided by others because of its brittleness.

Sea Water Pipes

Failures in sea water pipes were due to internal corrosion, soil corrosion and external corrosion under piers. The failures reported were not extensive although in case B-I (Appendix B, Table VI) a large system has become a major maintenance problem due to graphitization. It is difficult to remedy this situation but new installations can avoid the trouble through the use of asbestos-cement pipe or cement lined steel. With regard to external corrosion, the remarks previously made concerning fresh water pipes are applicable.

Natural Gas Pipes

All six cases of gas pipe failures described in Appendix B, Table VII, were due to soil corrosion and some of them were very costly. Excellent coatings were used on most of these installations but it has been well demonstrated that when the soil is highly corrosive a good coating will not guarantee protection. As the Federal Construction Council reported[10] for protective coverings "... because of the high incidence of mechanical damage, which is not covered by existing criteria, it is also concluded that laboratory tests for resistance to abrasion and puncture, and 'holiday'

tests for coverings after installation should be developed." Until such 'holiday' tests have been perfected, the findings indicate that cathodic protection is a practical solution for protecting steel pipe in a corrosive soil. The use of plastics pipe as mentioned under the section on Plastics Pipes may eventually solve the problem.

Fuel Oil Pipes

Oil is a valuable commodity and for this reason it is not difficult to justify the use of cathodic protection on all fuel lines. The most serious corrosion failures reported were cases F-I and F-II (Appendix B, Table VIII) where cathodic protection had not been installed. Corrosion under piers, cases F-III, F-IV, and F-V, is a more aggravating problem. Some of the coatings being tested on an above ground section of the Key West aqueduct* are highly satisfactory and might be considered for pipes under piers (see case W-XII, Appendix B, Table V).

Sewer Pipes

Cases D-I, D-II and D-III (Appendix B, Table IX) describe failures of cast iron, concrete and asbestos-cement pipes. In all cases the crown of the pipes failed from apparent attack by sewer gases.

This type of failure is characteristic of fairly long systems installed with a minimum grade. In such cases the sewage has a low velocity and becomes septic in the pipe, releasing gases such as hydrogen sulphide which attack the pipe. Insufficient venting and warm temperatures accelerate the septic process. Vitrified clay, epoxy lined asbestos-cement and polyvinyl chloride lined concrete are recommended for such installations. PVC has not been widely used for sewer lines but Reference 11 describes a highly successful installation with details of construction techniques which should make it competitive for all cases. Many Naval activities must contend with small slopes in their sewer systems and should, therefore, avoid the use of any pipe subject to sewer gas attack. The damage to pumps described in case D-IV is another example of unfortunate design.

Plastics Pipes

Although the use of plastics pipe is quite restricted under BUDOCKS instructions this study revealed at least ten different applications.

The most extensive use of plastics pipe, generally PVC or ABS is for service lines on potable water systems. In corrosive soil areas where galvanized pipes were unsatisfactory the substitution of plastic has been

*The aqueduct test coatings were applied in October 1959 under contract to BUDOCKS (subproject NY450 004-22).

a real money saver. Cases P-I, P-II and P-III (Appendix B, Table X) are test installations of condensate pipes employing two kinds of epoxy-glass. Cases P-IV and P-XII are examples of PVC and polyethylene being used under piers, and more such installations are planned at the Naval Station in Key West. These installations should be followed closely by those activities which have this corrosion problem. Case P-VIII illustrates the successful use of epoxy-glass in sea water. Although the initial material cost in this case was almost four times greater than steel it has now proved to be a more economical installation. A highly successful use of plastics pipe is in lawn sprinkler systems where the use of fertilizers and frequent waterings have played havoc with ferrous pipe.

An interesting use of plastic is described in case P-XVI where schedule 80 PVC was permitted in a propane system. Under normal circumstances, BUDOCKS does not permit the use of plastics pipe for gas lines and neither do some of the gas companies. However, both PVC and acetal types are being used for this service in commercial installations. One acetal installation in Louisiana consists of 5-1/2 miles of transmission pipe and over eleven miles of distribution networks. PVC is being used for gas pipes in several communities in Iowa and Nebraska. At the present time cathodic protection is required on miles of steel gas pipe at Naval activities, so it appears that research should be continued in the use of plastics pipe for gas service. Other applications include drains and vent stacks, cable ducts, brine lines and downspouts.

FINDINGS

1. Most activities visited have at least some areas where the soil is very corrosive.

2. Failures in underground heat distribution systems located below the water table constituted the most serious corrosion problems encountered in the study.

3. Heat distribution systems located in trenches above the water table have experienced very little corrosion resulting from the external environment.

4. The use of neutralizing amines has greatly reduced the incidence of internal corrosion in condensate lines; however, where make-up rates are high the amine treatment may not be the most economical method.

5. In several test sites, epoxy-glass has given excellent service in gravity flow condensate lines.

6. Pipes under piers are a problem at most shore establishments.

7. Sewer systems installed with minimum slope suffered failures when the pipes were not resistant to sewer gas attack.

8. Many activities, particularly along the Pacific and Gulf coasts, rely heavily on cathodic protection for their underground ferrous piping systems.

9. In coated pipe systems, the coatings were frequently damaged during installation and pipe joints were not always properly covered after being welded in the field. This led to corrosion and the necessity of applying cathodic protection.

10. The use of dissimilar metals due to poor design has resulted in many failures on water and gas service lines.

11. The use of asbestos-cement and plastic materials has been highly successful for cold water systems.

CONCLUSIONS AND RECOMMENDATIONS

1. Tighter specifications are needed for copper tees installed in asbestos-cement water mains. The results of this survey indicate, however, that cast iron fittings can be used in such installations.

2. Sewer pipe subject to sewer gas attack, such as unlined asbestos-cement, should not be used in systems with minimum slope; however, vitrified clay or epoxy lined asbestos cement are satisfactory. Also suitable are styrene rubber and polyethylene pipe which are covered by existing Department of Commerce Standards.

3. Epoxy-glass pipe, either cast or laminated, should be permitted for use in gravity flow condensate lines.

4. In selecting pipe coatings for pipes above ground, the Key West Aqueduct test coatings should be considered.

5. The economy of using non-ferrous materials in the condensate return line, or of dumping the condensate, should be investigated when designing a steam system with a high makeup rate requiring considerable amine treatment.

6. The information given in Type Specification TS-P28e 1962 concerning soil corrosivity and the use of cathodic protection should be more complete. It should include the information "if readings indicate significant differences in soil resistivity of the soils which will be in contact with the pipe, that a detailed investigation for cathodic protection should be undertaken."

7. Failures of prefabricated steel conduits for heating systems probably would have been less frequent if cathodic protection were adequately used in these installations.

8. Noncorrosive materials suitable for fabricating conduit for underground heating systems are available but techniques are lacking.

9. Concrete trenches where properly located have proved to be a good investment.

10. Great savings could be made by placing more pipes above ground, particularly where the water table is high and the soil corrosive.

11. The designs for new piping systems should be reviewed by competent corrosion engineers before installation.

12. An improved accounting of maintenance costs would separate the amounts actually spent on corrosion repairs, making it possible to predict future rates of corrosion failures. Such information is important for programming pipeline replacements.

13. Noncorrosive materials in some piping systems have not only reduced the cost of repairs and replacements but have removed the burden of providing coatings and cathodic protection. The ultimate objective should therefore be the use of noncorrosive materials in all piping systems.

14. For gas, fuel, hot water and condensate piping systems, research and field testing on plastics pipe should be vigorously pursued.

15. Pipes under piers should be treated as a special problem because pier construction and pipe hangers need to be considered in conjunction with the pipe material.

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Appendix A

Table I. Soil Data

Location	Resistivity (ohms per cu cm)	Water Table (ft)	Characteristics
Naval Air Station Jacksonville, Fla.	400 to 25,000 generally 15,000	4 to 5	Predominantly sand - well drained.
Naval Shipyard Charleston, S. C.	23 at 12' depth 21,400 at 4' depth	--	Some hydraulic fill. Areas with low resistivities at all depths.
Hqs. Support Activity New Orleans, La.	550 to 4000 average - 2,500	4 to 6	-----
Naval Air Station Beeville, Texas	960 to 9,500	--	Hard alkaline soil.
Naval Air Station New Orleans, La.	500	3	Old marsh drained and filled. Acid soil.
Naval Station Key West, Fla	250 to 200,000	6	White coral.
Mare Island Naval Shipyard Vallejo, Calif.	200 to 25,000 but generally less than 5,000	--	Mixed soil - much of it is fill over salt water marsh.
Naval Air Station Alameda, Calif.	--	--	Dredge fill.
Naval Air Station Whidbey Island, Wash.	Broad range of values with abrupt changes	--	Neutral or slightly acid.
Naval Supply Depot Seattle, Wash.	92 to 76,000	--	Sandy gravelly near surface - clay underneath.

Table I. Soil Data (continued)

Location	Resistivity (ohms per cu cm)	Water Table (ft)	Characteristics
Naval Air Station Sand Pt., Seattle, Wash.	8,000 to 45,000	--	Sandy gravelly.
Puget Sd. Naval Shipyard Bremerton, Wash.	2,000 to 635,000 generally over 12,000	--	Sandy gravelly with some clay.
Naval Supply Center Pearl Harbor, Hawaii	Generally low, indicating corrosive soil	--	Mixed coral, volcanic soil, clay, dredged material. Varying moisture conditions.
Naval Shipyard Pearl Harbor, Hawaii	--	--	Generally the same as the Naval Supply Center above.
Marine Corps Air Station Kaneohe, Hawaii	--	--	Soil of different physical characteristics. Corrosive in Capehart area.
Naval Air Station Barbers Point, Hawaii	--	--	Mildly corrosive but sharp changes in resistivity.
Naval Station San Diego, Calif.	100 to 30,000 (500 tests)	--	Primarily sand with considerable quantities of clay mixed with sand. Highly variable.
Naval Station Long Beach, Calif.	--	about 3-0	Dredged fill.
Naval Air Station Lemoore, Calif.	low	7.5	Station located on old lake bed - soil alkaline.
Naval Security Group Act. Skaggs Island, Calif.	40 to 200 (extremely corrosive)	--	Saline soil.

Table I. Soil Data (continued)

Location	Resistivity (ohms per cu cm)	Water Table (ft)	Characteristics
Naval Air Station Pt. Mugu, Calif.	Out of 157 tests 23.6% were extremely corrosive, 28% were severly corrosive	3.5 to 6.0	Large amount of fill. Fill not corrosive but underlying swamp has low resistivity.
NOTS China Lake, Calif.	225 to 10,000	3.0 to 60.0	Offices and homes are on high ground where sandy soils are only mildly corrosive and water table is 30 to 60 feet. Range area is old lake bed with water table as high as 3 feet.

Appendix B

CASE HISTORIES

Table II. Steam Pipes

Case No.	Type of Failure	Conduit/Envelope	Location	System Information	Comments
S-I	Condensate pipe and conduit corrosion	Prefabricated steel conduit	Headquarters Support Activity New Orleans, La.	In 1942, 48,000' of steam and condensate pipes encased in metal conduit were installed underground.	Between 1950 and 1960 the condensate line failed internally and the leakage caused corrosion to both the exterior of the condensate pipes and interior of the casing. The condensate pipes were abandoned. See case C-X. The cost of replacing the casing was higher than the PWO was prepared to pay, consequently the breaks were covered with an insulating hydrocarbon.
S-II	Condensate pipe and conduit corrosion	Prefabricated steel conduit	Naval Air Station Jacksonville, Fla.	A few years ago 19,000' of steam pipe encased in steel conduit were installed underground.	In approximately five years the system was ruined by corrosion which was attributed to the following factors: poor joints in the conduit, failure of the condensate line in the same conduit, and water back-up from manholes. A new system was installed using trenches in some areas and overhead racks in others. The new system is giving excellent service.
S-III	Conduit corrosion	Prefabricated steel conduit	Naval Shipyard Charleston, S. C.	In 1947, and in 1956-57, a total of 7,000' of steam pipe encased in metal conduit were installed underground.	In 1955, 900' of the original conduit had failed and was replaced with a new cast iron conduit. The cast iron was unsuccessful because it leaked at the joints. Failure of the original casing was partially due to internal pipe corrosion. The newer conduit is steel and part of it is in good condition but much of it was described as being a mess.
S-IV	Condensate pipe, steam pipe and conduit corrosion	Prefabricated steel conduit	Naval Air Station Whidbey Island, Wash.	In 1946, 1600' of steam and condensate pipe encased in a steel conduit filled with an insulating hydrocarbon, were installed underground. Steam and condensate pipes were both of black steel.	Within six years the exterior of the casing failed, the interior of the condensate line failed and the exterior of the steam line failed. Most of the system was replaced with steel steam lines and extra strong wrought iron returns encased in half tile set on a concrete base. No further problems have been reported.
S-V	Conduit corrosion	Prefabricated steel conduit	Naval Supply Depot Seattle, Wash.	In 1943, 1000' of steam pipe encased in steel conduit were installed underground.	In 1956 the casing was badly corroded and the line was abandoned.
S-VI	Conduit corrosion	Prefabricated steel conduit	Naval Station San Diego, Calif.	During the period 1942-48, 40,800' of steam and condensate pipe encased in a steel conduit were installed underground.	In 1961, during a corrosion survey, an engineering consulting firm discovered many large holes in the conduit. Although no leaks had occurred in the piping, the heat losses from the pipes were obviously much greater than the original design called for. The consulting firm did not make any recommendations in this case.
S-VII	Conduit corrosion	Prefabricated steel conduit	Naval Station Long Beach, Calif.	In 1948, 300' of steam and condensate pipe encased in a steel conduit were installed underground.	Within five years the conduit had failed, presumably as a result of stray currents. It was replaced with vitreous clay pipe which has worked satisfactorily.
S-VIII	None	Prefabricated steel conduit	Naval Station Long Beach, Calif.	In 1953, 600' of steam pipe encased in steel conduit were installed underground.	The system is giving excellent service. (No cathodic protection)
S-IX	None	Steel snap-on jacket, compressurized	Marine Corps Air Station Kaneohe, Oahu, Hawaii	In about 1944, 3600' of steam pipe encased in a steel conduit filled with an insulating hydrocarbon, were installed underground, but above the water table and given cathodic protection.	After 20 years the system is giving excellent service.

Table 11. Steam Pipes (continued)

Case No.	Type of Failure	Conduit/Envelope	Location	System Information	Comments
S-X	Steam pipes and trench	Concrete trench	Naval Station Key West, Fla.	Steam pipes originally installed in 1945, are in trenches leading from the boiler plant to the piers.	In early years the trenches were not kept clear of mud and water with the result that external corrosion ruined the steam pipes. The pipes were replaced in 1958-59 and a program started to keep trenches open. There has been no further trouble except where reinforcing rods have corroded causing 200' of trench to collapse.
S-XI	Same	Concrete trench	Naval Air Station Jacksonville, Fla.	Approximately 19,000' of steam pipe were installed in trenches.	The trenches are designed for quick drainage so they are rarely flooded, consequently the pipes and insulation are in good condition.
S-XII	Insulation	Concrete trench	Naval Shipyard Charleston, S. C.	11,000' of steam pipe with insulation of either cellular glass or 85% magnesia were installed in trenches.	Because of a difficult drainage problem, the trenches are frequently flooded causing damage to the insulation. The pipes themselves are in good condition but they experience a high heat loss during wet weather.
S-XIII	Same	Concrete trench	Naval Supply Depot Seattle, Wash.	In 1943-44, approximately 20,000' of steam pipe were installed in trenches.	These lines have been practically trouble-free for 20 years.
S-XIV	Same	Concrete tunnel	Puget Sound Naval Shipyard Bremerton, Wash.	Approximately 59,000' of steam pipe in tunnels.	After many years these pipes are still in good condition.
S-XV	Same	Concrete trench	Naval Station San Diego, Calif.	In 1958, 9300' of steam and condensate pipe were installed in trenches.	To date no trouble has been experienced with these systems.
S-XVI	Same	Concrete trench	Naval Air Station North Island, San Diego, Calif.	In about 1941, 21,000' of steam pipe were installed in trenches.	Very little trouble has been experienced with these systems.
S-XVII	Trench	Concrete trench	Naval Shipyard Pearl Harbor, Oahu, Hawaii	Concrete trenches built in 1941 carry 4 to 12-inch steam pipe.	The steam pipes did not fail but reinforcing bars in the concrete became badly corroded. By 1958 the concrete was spalling from the top and sides and falling into the trench.
S-XVIII	Condensate pipes	Concrete trench	Naval Air Station Sand Point, Seattle, Wash.	Approximately 14,000' of trench carrying steam and condensate pipe have been in place for over 20 years.	The steam pipes have experienced no corrosion failures. The condensate pipes are now developing leaks resulting from internal corrosion but the trenches have served their purpose very well.
S-XIX	Steam pipes	Concrete trench	Naval Academy Annapolis, Md.	Steam and condensate lines are located in trenches which are very humid and frequently flood with brackish water. Calcium silicate insulation is used on the steam pipes.	When the trenches flood, the normal steam load of 220,000 lb/hr rises to 370,000 lb/hr. When the water retreats the calcium silicate dries out and recovers its insulation properties but the pipe is beginning to corrode under such harsh treatment.
S-XX	Same	Tile conduit	NOTS China Lake, Calif.	Several thousand feet of steam pipes were installed in tile conduit sometime prior to 1946.	This system is located on high ground well above the water table and has given excellent service.
S-XXI	Same	Tile conduit	Naval Station Long Beach, Calif.	In 1953, 600' of steam and condensate pipe were installed in split tile conduit.	This system has given excellent service but is considered too expensive for present day usage.
S-XXII	Same	Insulating hydrocarbon	Naval Station San Diego, Calif.	In 1956, 3400' of steam pipe were buried in an insulating hydrocarbon under strict supervision.	This system has given excellent service and the local engineers feel that the great care taken during installation is partially responsible.
S-XXIII	Condensate pipes and casing	Insulating hydrocarbon	NOTS China Lake, Calif.	In 1948, 1130' of high pressure steam and condensate pipe, encased in prefabricated steel conduit, were installed underground.	After 7 years both the casing and condensate pipes were corroded beyond repair. A new system was installed in which the pipes were enveloped in an insulating hydrocarbon. The cost of the new system was $20,682, and it is giving excellent service.

Table III. Condensate Pipes

Case No.	Type of Failure	Conduit/Envelope	Location	System Information	Comment
C-I	Internal corrosion	Trench (partial)	Naval Air Station Dallas, Tex.	Condensate return lines are located in trenches or on overhead racks. Make-up water about 25%. Amines not used prior to FY-65.	As a result of internal corrosion the lines were replaced twice in 12 years. Corrosion testers installed in the pipes failed to detect the occurrence of corrosion.
C-II	Internal corrosion	Tunnel	Puget Sound Naval Shipyard Bremerton, Wash.	36,000' of condensate pipe installed in tunnels with many feet inside buildings. Originally these lines were of ferrous material.	During a four-year period (1956-60) the cost of condensate pipe replacements averaged $25,000 per year. Most of the replacements were inside buildings and were largely copper and brass. A study of the system by the district office showed 920 million lbs steam per year being produced with make-up of 78.8%. Cost of using neutralizing amines estimated at $10,250 per year. Although corrosion was greatly reduced through the use of amines it might have been more economical to gradually replace all ferrous condensate lines with copper and save cost of amine treatment.
C-III	Internal corrosion	Metal conduit	Naval Training Center San Diego, Calif.	2000' of steel condensate pipe were buried inside a metal conduit.	The steel pipe failed internally but metal conduit remained intact. New copper pipe was pulled through conduit to serve as new condensate pipe.
C-IV	Internal corrosion	Trench	Naval Station Key West, Fla.	1675' steel condensate pipe from laundry and galley to boiler plant were located in a trench. No amines were used.	Within 9 months pipe failed internally and was replaced with wrought iron.
C-V	Internal corrosion Dissimilar metals		Naval Supply Depot Seattle, Wash.	Inside the buildings at this activity are typical systems with steel pipes connected to brass traps.	In recent years numerous failures have occurred where the pipes join the traps. The installations have been in place only 5 or 6 years. Neutralizing amines were not being used.
C-VI	Internal corrosion		Naval Air Station Memphis, Tenn.		Entire condensate system is badly deteriorated and an estimated $200,000 required to replace it. Value of condensate is about $25,000 per year, consequently engineers at SOEASDIVDOCKS feel it might be more economical to dump the condensate than to replace and maintain a new system.
C-VII	Internal corrosion		Naval Air Station Barbers Point, Oahu, Hawaii	In 1952, 1000' of steel pipe varying in size from 3/4" to 6" were installed aboveground. Neutralizing amines and ion-exchange water softeners were reported in use.	In 1956 the pipe failed internally and had to be replaced. Cause was attributed to CO_2 channelling.
C-VIII	Internal corrosion	Tunnel	Naval Station Long Beach, Calif.	In 1942-44, 1600' of X-strong wrought iron pipe, 1-1/2" to 3", were installed in tunnel.	In 1946 the pipe failed due to internal corrosion. Lack of water treatment was blamed for rapid corrosion.
C-IX	Internal and external corrosion	Terra-cotta conduit	NOTS China Lake, Calif.	Condensate pipes were originally in terra-cotta conduit.	The lack of an early water treatment program led to internal failures in the condensate pipes and the leakage of condensate into the conduit led to external failures of the pipes. 22,800' which were replaced in insulating hydrocarbon have been successful for 8 yrs.
C-X	Internal and external corrosion		Headquarters Support Activity New Orleans, La.	Originally this activity had 52,000' of condensate pipe, of which 48,000' were underground.	Corrosion, both internally and externally, was so extensive all pipes have been abandoned. Engineers in the district office feel it is cheaper to provide 100% make-up rather than install and maintain new condensate pipe.

Table III. Condensate Pipes (continued)

Case No.	Type of Failure	Conduit/Envelope	Location	System Information	Comment
C-XI	Internal and external corrosion	Concrete trenches	Naval Air Station Corpus Christi, Tex.	Originally the condensate pipes were located in concrete trenches 4'x 4'.	Trenches, acting as storm sewers, were frequently filled with water, causing external corrosion to pipes. Today, approximately 75% of pipes are on above ground hangers but in bad condition externally. Estimated cost of replacement is $278,000.
C-XII	External corrosion	Concrete trench	Mare Island Naval Shipyard Vallejo, Calif.	In 1956, 250' of 6" wrought iron (X heavy) pipe were installed in concrete trench and covered with insulating hydrocarbon.	In 1959 the exterior of pipe failed. Cause of failure attributed partly to stray currents and partly to moisture infiltrating the hydrocarbons. Pipe was replaced, bonded and grounded, and covered with different type of hydrocarbon. No further trouble reported. Mare Island has approximately 40% make-up and does not use amines.
C-XIII	External corrosion	Galvanized steel conduit	Naval Station Long Beach, Calif.	In 1948, 300' of 3" steel pipe were installed in galvanized steel conduit.	Within 5 years both conduit and pipe were badly corroded. Stray currents probably cause of failure. A new wrought iron condensate pipe was placed in vitreous clay conduit and no further trouble reported.
C-XIV	External corrosion		Naval Station San Diego, Calif.	In 1961, 535' of 3" steel pipe covered with asphalt emulsion and roofing material (MIL-C-15203B) were buried directly in ground.	Within 2 years outside of pipe had failed in many places. Engineers on station believed that stray currents were contributing factor.
C-XV	External corrosion	Concrete trench	Naval Station San Diego, Calif.	700' of 3" steel pipe, uncoated, were buried directly in ground.	Within 4 years, pipe was ruined from external corrosion and replaced with copper pipe in concrete trench.

Table IV. Hot Water Pipes

Case No.	Service and Type of Failure	Conduit/Envelope	Location	System Information	Comments
H-I	Hot water heating No failure	Trench	Naval Shipyard Charleston, S. C.	Heating system consisting of 2600' of steel pipe installed in 1910. Pipe was replaced in 1956.	Although trench was expensive, it protected first piping system for 46 years and will probably give equal protection to second system.
H-II	High temperature hot water heating Insulation failure	Trench	Naval Air Station Lemoore, Calif.	In 1960, a high temperature hot water steel pipe system valued at $1,000,000 was installed. Part of pipe was in prefabricated steel conduit, but most of it was in trenches. Original insulation was calcium silicate bound with a canvas jacket.	Much of system was below water table resulting in flooding of trenches. In 2-1/2 years it was estimated that 25% of insulation had fallen off pipes, heat loss was costing $26,000 per year, and outside of pipes were beginning to corrode. Temperature and humidity in manholes made it impossible to work on system without shutting off heat. To remedy situation, cisterns were dug to collect water from trenches and manholes. When water cools it is pumped out. Insulation is being replaced with waterproof protective covering.
H-III	Domestic hot water No failure	Tunnel	Puget Sound Naval Shipyard Bremerton, Wash.	Many years ago, 9510' hot water steel pipe were installed in Bremerton tunnels.	Although system is very old it is still satisfactory.
H-IV	Hot water heating Conduit and external pipe corrosion	Prefabricated steel conduit	Naval Air Station Point Mugu, Calif.	In 1958, 2000' low temperature hot water steel pipe were buried in a prefab steel conduit.	In 3 years the casing and exterior of the pipes were corroded beyond repair. Cost of replacing system with same type of installation was $70,000. Because of high cost the use of underground pipe was discarded in favor of individual boilers in each building.
H-V	High temperature hot water heating Conduit corrosion	Prefabricated steel conduit	Naval Air Station Lemoore, Calif.	In 1960, part of large high temperature hot water system was installed in prefab steel conduit. See Case II.	In 2-1/2 years a section of trench was dug up to make repairs. It was discovered that several feet of the steel conduit leading to trench was badly corroded.
H-VI	Domestic hot water No failure	Steel envelope jacket, non-pressurized	Marine Corps Air Station Kaneohe, Oahu, Hawaii	About 1944, 5200' domestic hot water steel pipes, insulated and buried in steel jacket in which annular space between insulation and jacket was filled with insulating hydrocarbon, was installed above water table and given cathodic protection.	After 20 years the system is giving excellent service.
H-VII	Hot water heating, and domestic hot water Internal and external pipe corrosion	Tile conduit	NOTS China Lake, Calif.	Four pipes comprising hot water heating supply and return, and domestic hot water supply and return, were installed in tile conduit filled with calcium silicate insulation. About 1/2 of system was black steel and remainder was galvanized steel. Installation made in 1947 was approximately 3800' in length.	By 1962 the domestic water pipe had failed from the inside and soaked the insulation, which eventually led to corrosion of exterior of all four lines. System investigated by consulting engineer from Long Beach, Calif., who recommended the pipes be replaced in shallow concrete trenches. Independent study made by the consulting engineer revealed that within the SOWESTDIVDOCKS trenches were much more economical than prefabricated steel conduit when considered over period of 15 to 20 years.
H-VIII	Hot water heating No failure	Insulating hydrocarbon	NOTS China Lake, Calif.	In 1958, 20,000' hot water heating steel pipe were buried in insulating hydrocarbon. Pipe is located on high ground well above water table.	System cost $17.50 per ft. and the engineering personnel feel it was good investment although it has not been in place long enough for a full evaluation.
H-IX	High temperature hot water External pipe corrosion	Insulating concrete	Naval Air Station Whidbey Island, Wash.	In 1951, 6000' of high temperature hot water steel pipe were buried in envelope of insulating concrete.	By 1960 it was necessary to replace entire system. Moisture had penetrated concrete and corrosion occurred on exterior of pipe, particularly where wooden spacers had been buried with pipe. Pipes were replaced in concrete trenches.
H-X	Domestic hot water External pipe corrosion	Floor slab	Naval Station Key West, Fla.	Domestic hot water pipe of galvanized steel was buried in floor slabs of 1400 homes.	Galvanized steel began corroding from outside and it appears it will be necessary to replace pipe with overhead copper pipe in all 1400 homes.

Table [illegible]. Hot Water Pipes (continued)

Case No.	Service and Type of Failure	Corrective Procedure	Location	System Information	Comments
[illegible]	Domestic hot water [illegible]		Naval Air Station Barbers Point, Oahu, Hawaii	In 1957, eight barracks were built using galvanized iron pipe in the domestic hot water system.	Soon after barracks were completed, leaks began to appear where pipe came in contact with brass valves and system began to clog up with iron oxide deposits. Lack of insulating fittings between valves and pipes contributed to accelerated corrosion. Approximately 7500' were subsequently replaced with copper.

Table V. Cold Water Pipes

Case No.	Service and Type of Failure	Pipe Material	Location	System Information	Comments
W-I	Domestic water Copper tee failure	Asbestos-cement	Naval Air Station Lemoore, Calif.	10- and 14-inch asbestos-cement water pipes were installed with copper tees which had soldered joints. Working pressure in pipe varied from 70 to 125 psig.	After 3 months of operation the tees began to fail. In approximately 3 years 146 tees were replaced at cost of $54,000. The tees appeared to have ruptured from pressure surges, but it was opinion of corrosion engineers from 12ND that stress corrosion was a contributing factor. They were replaced with CI tees which have given satisfactory service.
W-II	Domestic water Copper tee failure	Asbestos-cement	Naval Air Station Point Mugu, Calif.	8- and 10-inch asbestos-cement water pipes were installed with copper tees which had soldered joints. Usual water pressure is 125 psig.	During the first year from 20 to 25 tees failed. Failures were attributed to galvanic corrosion at the soldered joints. CI tees were used as replacements and no further trouble reported.
W-III	Domestic water Copper tee failure	Asbestos-cement	Marine Corps Air Station Kaneohe, Hawaii	In 1959, 6- and 10-inch asbestos cement pipes were installed in Capehart housing area, with a total of 90 copper tees.	In 1960, 9 tees failed; 1961, 5 failed; and in 1962, 4 failed. Public Works personnel stated failures appeared to be caused by separation of joint due to internal water pressure and not to corrosion. Cost of replacing failures with CI tees was $5400.
W-IV	Domestic water Copper tee failure	Asbestos-cement	Naval Air Station Boca Chica, Fla.	200 copper tees used in a 6- and 8-inch asbestos-cement pipeline.	Twenty tees split at soldered seams.
W-V	Lawn sprinkler Soil corrosion	Galvanized steel	Naval Station San Diego, Calif.	System installed in 1956. Galvanized steel used for lawn sprinkler system covering area of 35 acres.	Within 6 years the number of leaks occurring in system was very high, and a consulting engineer was asked for advice. He found extensive and severe corrosion due to galvanic action. Dissimilar metals, low resistivity soil, application of fertilizers, and lawn watering all contributed to rapid deterioration of the system. He recommended system be replaced with asbestos-cement, or PVC, at estimated cost of $300,000.
W-VI	Domestic water Soil corrosion	Asbestos-cement	NOTS China Lake, Calif.	In one of the new housing areas the water pipes are of asbestos-cement, and the 1-1/2-inch service pipe of galvanized steel with tar coating.	Within one year leaks occurred in three service pipes due to galvanic corrosion. Resistivity of soil is highly variable in area.
W-VII	Domestic water Soil corrosion	Galvanized steel	Public Works Center Pearl Harbor, Hawaii	System installed in 1960. In the McGrew housing area the service pipes are galvanized steel (3/4- to 2-inch).	From 1961 through 1963, total of 20 leaks occurred involving 1200' of service pipe. Leaks resulted from external corrosion due to galvanic action in corrosive soil.
W-VIII	Domestic water Soil corrosion	Galvanized steel	Naval Ammo Depot Lualualei, Hawaii	In 1959, galvanized steel service pipes were installed under concrete slab floors in Capehart housing development.	In the first year 12 leaks occurred. In some cases the zinc coating had been scratched off the pipe by a wrench near the slab and were repairable. In four cases new pipes had to be installed in the attic.
W-IX	Domestic water Soil corrosion	Mostly steel with bituminous coating	Naval Air Station Point Mugu, Calif.	By 1956, Point Mugu had elaborate underground pipe system. Water lines were mostly steel with bitumastic coating.	Because of frequent leaks in the water pipes a consulting engineer was retained in 1949, again in 1956. Parts of system were replaced with asbestos-cement and as a result of consultant's advice, cathodic protection installed in remainder of system. Soils are highly corrosive in most areas, but cathodic protection has prevented further trouble. One of the contracts for asbestos-cement replacement was for $25,000, while complete cathodic protection of water and gas pipes to sled only $42,000.
W-X	Domestic water Soil corrosion		Marine Corps Air Station Kaneohe, Hawaii	In the Capehart area each wrought iron lateral from the transite water pipe is connected to a brass plug-cock, an iron section, then to a brass pressure reducing valve at each residence.	The wrought iron sections being anodic to the brass, corroded, and failed at rate of about ten per year. Cost of replacing with copper was approximately $3000 per year.
W-XI	Lawn sprinkler Soil corrosion	Galvanized iron	Naval Air Station Barbers Point, Hawaii	In 1958, an irrigation system was installed consisting of 4300' of galvanized iron with brass shut off valves.	As result of external corrosion from galvanic action it was necessary to replace entire system in 1962.

Table V. Cold Water Pipes (continued)

Case No.	Service and Type of Failure	Pipe Material	Location	System Information	Comments
W-XII	Domestic water Soil corrosion	Steel	Key Aqueduct Key West, Fla.	In 1941-42, approximately 102 miles of 18-inch diameter coated steel pipe was buried within the right-of-way of the overseas highway. Original coating was rag felt shielded, modified grade, hot applied coal tar enamel.	Coating suffered severe damage from shrinkage of felt prior to laying pipe, and additional damage during installation. In 1957, team of engineers made study of pipeline and, among many recommendations, was one for replacement of 1.6 miles of the pipe approaching the Naval Station, and the installation of cathodic protection on entire 102 miles. At present time, through use of zinc and magnesium anodes, corrosion has been brought under control. With leakage reduced to about 10% of what it was before cathodic protection, the aqueduct engineers feel pipeline is now in good condition.
W-XIII	Domestic water Soil corrosion	Cast iron	Mare Island Naval Shipyard Vallejo, Calif.	In 1945, an 8-inch cast iron water pipe was installed. Cast iron bolts were used at joints.	Although the bolts were cast iron they were apparently anodic to the pipe and by 1955 they had failed on 1250' of pipeline. Bolts were replaced, joints bonded and cathodic protection added. No further trouble has been experienced.
W-XIV	Domestic water Soil corrosion	Galvanized steel	Naval Security Group Activity Skaggs Island, Sonoma, Calif.	In housing area 1-3/4-inch diameter galvanized steel service pipe connected asbestos-cement mains to the residences. Pipes, each 20' in length, were installed in 1961.	Within nine months, 40 of the service pipes failed and were replaced with PVC. The soil in this area highly corrosive.
W-XV	Domestic water Soil corrosion	Cast iron	Naval Air Station Corpus Christi, Tex.	In 1941 a bell and spigot cast iron system was installed.	Failures in the line gradually increased and after approximately 20 years, 7000' of pipe were replaced with asbestos-cement. The replacement had to follow a different route requiring 8400' at cost of $9300. Original pipe was badly graphitized.
W-XVI	Domestic water Soil corrosion	Asbestos-cement	Naval Air Station New Orleans, La.	In 1956, an asbestos-cement pipe with cast iron fittings, valves and pumps, was installed. The valves and pumps which both had CI housings were fastened with steel bolts.	In three to seven years, 20 valves and 6 pumps were disabled when bolts became severely corroded. It was necessary to replace steel bolts with brass bolts in 180 cases.
W-WVII	Domestic water Corrosion under piers	Black steel	Naval Supply Depot Seattle, Wash.	In 1947, 3500' of 8-inch black steel pipe were installed (pipe covered with hair felt and subject to salt spray).	In 10 years the outside of pipe badly corroded and replaced in 1958 with asbestos-cement for $30,000. Use of asbestos-cement, avoided by most activities for under pier installations because of its brittleness, was successful in this case.
W-XVIII	Fire sprinkler system Corrosion under piers	Black iron	Naval Supply Depot Seattle, Wash.	In 1943, 20,000' of 1- to 6-inch black iron pipe were installed as a dry sprinkler system. It had no coating and was subject to salt spray.	By 1960, exterior was severely corroded and the system was replaced with galvanized steel for $20,000.
W-XIX	Domestic water Corrosion under piers	Black steel welded	Naval Air Station Whidbey Island Oak Harbor, Wash.	In 1942, black steel welded pipe coated with asphalt was installed under pier approximately 6' above the high tide mark.	In 1962, pipe failed badly and replaced on the deck.

Table VI. Sea Water Pipes

Case No.	Type of Failure	Pipe Material	Location	System Information	Comments
B-I	Internal corrosion	Cast iron	Naval Air Station North Island San Diego, Calif.	Over past 10 to 20 years, 88,600' of cast iron salt water pipe were installed.	In the past 4 years the system has suffered an average of one break per month. Corrosion is internal and practically all breaks show evidence of graphitization.
P II	Soil corrosion	Cast iron	Mare Island Naval Shipyard Vallejo, Calif.	In 1945, a cast iron salt water pipe was installed in an old marsh area which had been filled.	In 1955, the pipe was leaking badly as a result of bolt failures at the joints. The bolts, which were anodic to the pipe, were replaced and put under cathodic protection. No further trouble was reported.
B-III	Internal and soil corrosion	Steel	Naval Station Key West, Fla.	Steel pipes which have been installed for quite a few years are used extensively for sea water fire lines.	The pipes are failing from both inside and outside at rate of one break per month; consequently, 75% of the pipes will be abandoned and fire wells used instead.
B-IV	Corrosion under pier	Steel	Naval Shipyard Long Beach, Calif.	In 1942, 1360' of 8-inch steel pipe were installed under pier.	In 14 years the pipe had failed from both inside and outside. It was replaced for $12,000, using cement lined steel pipe on the pier deck.

Table VII. Natural Gas Pipes

Case No.	Type of Failure	Pipe Material	Location	System Information	Comments
G-I	Soil corrosion	Wrought iron copper Galvanized steel bronze	Naval Auxiliary Air Station Beeville, Tex.	In 1958, a new Capehart housing development was supplied with gas from 2-inch wrought iron pipe. The laterals to each house comprised 50 feet copper pipe, 4 feet galvanized steel, and a bronze corporation cock.	By 1963, all of the 4-foot galvanized sections had failed internally and the wrought iron pipe was badly corroded. The galvanized sections were replaced with copper at cost of $20,000, and cathodic protection was installed on the pipe. Reference to the section on Soils confirms the likelihood of such failures. The design was done by an architect-engineer and reported to be in compliance with FHA requirements at that time.
G-II	Soil corrosion	Steel	Naval Air Station New Orleans, La.	In 1956, 9000' of 2-inch steel gas pipe were installed underground. The pipe was coated with one prime coat, two enamel coats, 15# felt, and a layer of heavy kraft paper.	In only 2 years the system was ruined by corrosion. 3000' were replaced by station personnel and 4400' were abandoned. Failure was attributed to poor workmanship in coating the joints after welding. Cathodic protection was installed on the new lines.
G-III	Soil corrosion		NASA Houston, Tex.	In 1962, 26,300' of 1- and 2-inch gas pipes were installed underground. The pipes were given a protective coating but details on the coating were not available.	Within 2 years 14,000' of the pipe had failed externally. Local engineers concluded the coating had been damaged during installation and in a corrosive soil this damage led to accelerated corrosion which ruined the pipe. It was replaced and given cathodic protection.
G-IV	Soil corrosion	Steel	Naval Security Group Activity Skaggs Island, Sonoma, Calif.	During World War II, 11,000' of 4-inch steel gas pipe were installed in very corrosive soil with no cathodic protection.	Within 2 or 3 years the complete system was ruined from external corrosion. It was replaced with 11,000' of 6-inch steel pipe but in a few years this pipe was also ruined. In 1952, the pipe was replaced with an 8-inch steel pipe and cathodic protection was added to system. No further failures have developed.
G-V	Soil corrosion	Steel	Mare Island Naval Shipyard Vallejo, Calif.	In 1945, 100' of 4-inch steel pipe were installed in a marsh fill area. The pipe was treated with bituminous coating 1/8-inch thick.	In 1955, there was a general external failure of pipe due to galvanic action. The pipe was replaced and put under cathodic protection.
G-VI	Soil corrosion	Steel	NOTS China Lake, Calif.	In 1956, 1- and 2-inch steel gas pipes were installed but the nature of the coating was not available.	In 1962, 270' of pipe failed externally. The pipes were replaced and cathodic protection was advised by SOWESTDIVDOCKS. As of November 1963 the cathodic protection had not been installed.

Table VIII. Fuel Oil Pipes

Case No.	Type of Failure	Pipe Material	Location	System Information	Comments
F-I	Soil corrosion	Steel	Naval Shipyard Charleston, S. C.	There are 50,000' of steel fuel pipe ranging from 6- to 20-inches in diameter installed throughout the shipyard.	The leaks in the system increased in number each year until in 1951 there were 18 leaks and in 1952 a peak of 35 leaks. Cathodic protection was installed and leakage rate immediately dropped and has since remained at three or four per year.
F-II	Soil corrosion	Ferrous	Pearl Harbor Naval Shipyard Oahu, Hawaii	Much of the fuel system ranging up to 24 inches in size was installed without cathodic protection during World War II.	By 1954 leaks were occurring frequently, but by 1958 cathodic protection had been applied to most of the system and the leaks brought under control. Most leaks occurred where coating had been punctured during installation.
F-III	Under piers	Ferrous	Naval Supply Center Pearl Harbor, Hawaii	During 1943 and 1944 a considerable length of 12-inch pipe was installed under piers.	Water, dripping on pipes from the pier deck, has led to severe corrosion.
F-IV	Under piers	Ferrous	Naval Air Station Whidbey Island, Wash.	In 1942, 4-, 6- and 8-inch oil and fuel pipes were installed under piers.	By 1962 the pipes had failed at their wooden supports. The pipes, involving total of 1500' were replaced on top of the deck.
F-V	Under piers	Ferrous	Puget Sound Naval Shipyard Bremerton, Wash.	Most of the shipyard fuel pipes are in tunnels where there is no problem with external corrosion. But there is considerable length under piers exposed to salt spray environment.	Corrosion has occurred to the pipe under piers 4, 5 and 6.

Table IX. Sewer Pipes

Case No.	Type of Failure	Pipe Material	Location	System Information	Comments
D-I	Internal	Cast iron	Naval Station Key West, Fla.	In 1950, an 18-inch cast iron effluent pipe was installed.	By 1963 the pipe had failed. The crown of the pipe corroded, apparently from the action of sewer gases.
D-II	Internal	Concrete	Naval Station Key West, Fla.	In 1942, 80' of 12-inch concrete raw sewage pipe were installed.	In 1962 the pipe failed. The crown of the pipe spalled and weakened, apparently from the action of sewer gases.
D-III	Internal	Asbestos-cement	Naval Air Station Jacksonville, Fla.	In 1940, a long asbestos-cement sewer line was installed in conjunction with several pumping stations. Part of the pipe was pressurized and part of it was gravity flow.	In 1955, 4000' of the gravity flow portion of the 10-inch pipe failed, and in 1960, 3000' of the gravity flow portion of the 8-inch pipe failed. The crown of the pipe which collapsed was apparently attacked by sewer gases.
D-IV Pumps	Galvanic corrosion	Cast iron steel	Naval Air Station New Orleans, La.	Sewage lift pumps with cast iron housings were installed with steel bolts.	Because of dissimilar metals the bolts corroded in two months. The resulting damage to eleven pumps cost almost $9000 to repair.

Table X. Plastics Pipes

Case No.	Service and Type of Failure	Pipe Material	Location	System Information	Comments
P-I	Condensate No failure	Epoxy-glass (cast)	Naval Research Laboratory Washington, D. C.	In 1958, 150' of 2-inch epoxy-glass (cast) condensate pipe were installed inside an NRL building for test purposes. Original steel pipe was installed in 1944 and replaced in 1950. Condensate is gravity flow at 170 to 180 F; hangers are spaced every 8 feet.	After 6 years, epoxy-glass pipe has given no problems. Steel pipe preceding the test pipe, which was also ne in 1958, has had two corrosion failures during this 6-year period. The cost of epoxy-glass is roughly 3-1/2 times the cost of the same sized steel pipe[12]
P-II	Condensate Epoxy-glass fittings failed under high pressure	Epoxy-glass (cast)	Naval Academy Annapolis, Md.	100' of 3-inch epoxy-glass (cast) condensate pipe were installed in a trench for test purposes. Pipe runs full at pressures up to 90 psi. Condensate is fed into pipe from high pressure traps at 135 psi and 365 F. Test line replaced a wrought iron pipe which failed from external corrosion in only 3 years. Trenches at Academy are very damp, frequently fill with brackish water creating a highly corrosive environment.	The epoxy-glass pipe has withstood this severe test for over 3 years but the epoxy-glass fittings failed mechanically. Admission of condensate into pipe creates a pressure pulse or water hammer causing the fittings to break. Wrought iron fittings are now being used as replacement. Under gravity flow there is of course no trouble with the epoxy-glass fittings.
P-III	Condensate No failure	Epoxy-glass (laminated)	Naval Air Station Treasure Island, Calif.	In August 1961, 130' of epoxy-glass (laminated) pipe were installed as a condensate test section. System is gravity flow with maximum temperature of 215 F.	Test section has been monitored by NCEL and a report[13] written on the details of the test indicates a very successful installation.
P-IV	Fresh water No failure	PVC	Pearl Harbor Naval Shipyard Oahu, Hawaii	In 1960, 250' of 3-inch PVC pipe were installed under the piers. Water is used to flush out submarine fuel tanks.	No problems have been reported.
P-V	Potable water No failure	ABS	Naval Station San Diego, Calif.	Approximately 20,000 feet of ABS pipe ranging from 3/4- to 4-inch diameter are used for potable water. It has been in place for 2 to 3-1/2 years.	No problems have been reported.
P-VI	Potable water No failure	PVC	Naval Air Station Lemoore, Calif.	All service pipes between water pipes (asbestos-cement) and buildings are made of PVC. Have been in place since the base was built in 1960.	No problems have been reported and they are considered invaluable in view of the corrosive soil.
P-VII	Potable water No failure	PVC	Naval Station San Diego, Calif.	6000' of 1-1/2-inch dia. PVC are used in their potable water system. It has been in use for 8 years.	No problems have been reported.
P-VIII	Potable water No failure	Epoxy-glass	Coast Guard Station San Diego Bay, Calif.	In 1957, 1500' of 5-inch epoxy-glass pipe were installed underwater between the Coast Guard Station and a buoy in the bay. Steel pipes previously used for this service had failed every 2 years.	The cost of this epoxy-glass pipe was almost 4 times that of steel but after 6 years of service it has proven to be more economical than installing a new steel line every 2 years.
P-IX	Potable water No failure	PVC	Naval Air Station Whidbey Island, Wash.	In 1958, approximately two miles of 2-inch PVC were installed for fresh water.	The system has given no trouble.
P-X	Potable water Galvanized pipes corroded	Galvanized steel and PVC	Naval Security Group Activity Skaggs Island, Sonoma, Calif.	In January 1961, galvanized steel laterals were installed between asbestos-cement water pipes and 40 homes. The laterals, which were each 20 feet in length, failed in 9 months due to galvanic action in a severely corrosive soil. They were replaced with PVC pipe.	No further trouble has been reported.

Table X. Plastics Pipes (continued)

Case No.	Service and Type of Failure	Pipe Material	Location	System Information	Comments
P-XI	Wells Galvanized pipes corroded	Galvanized steel and PVC	Naval Air Station Lemoore, Calif.	A corrosive situation was discovered in their wells where galvanized steel pipes were used to transfer pea gravel to the water inlet. Potential between galvanized pipe and well casing led to rapid deterioration of pipe. Was replaced with PVC.	No further trouble has been reported.
P-XII	Downspouts No failure	PVC	Naval Supply Depot Seattle, Wash.	In 1956 and 1957, 4-inch PVC downspouts were installed.	The atmosphere in this area is quite corrosive and the PVC makes an excellent substitute for wood or metal.
P-XIII	Air line No failure	Polyethylene	Naval Supply Depot Seattle, Wash.	In 1963, 5000' of 1-inch polyethylene were installed to carry compressed air under piers.	This pipe has not had the test of time but appears to be an excellent solution to a difficult problem.
P-XIV	Lawn sprinkler system No failure	Polyethylene	Naval Air Station Boca Chica, Fla.	The lawn sprinkler system for the station playing field utilizes polyethylene pipe.	No problems reported.
P-XV	Lawn sprinkler system No failure	PVC	Naval Air Station Point Mugu, Calif.	In 1959 a lawn sprinkling system was installed with PVC pipe up to 2-inch diameter.	The system works well with no problems.
P-XVI	Propane gas No failure	PVC	NOTS China Lake, Calif.	In 1957, permission was granted for the installation of 5280 feet of schedule 80 PVC pipe for carrying propane gas. The installation is down range where the soil is corrosive and the water table is only 2 or 3 feet below grade.	No problems were reported as of November 1963.
P-XVII	Brine line No failure	PVC	Naval Air Station Jacksonville, Fla.	In 1960, 1500 feet of 3-inch PVC pipe were installed to carry brine. System is located outdoors and above ground where it replaces a wrought iron pipe which failed externally in the same location.	As of October 1964, the pipe was giving excellent service.
P-XVIII	Cable ducts No failures	PVC	Naval Air Station Boca Chica, Fla.	PVC pipe, buried in concrete envelopes, is used extensively for cable ducts.	Personnel at Boca Chica prefer PVC to asbestos cement, fiber pipe or other materials for cable conduit because it is non-corrosive, water tight and economical to install.
P-XIX	Drains and vents No failure	Styrene-rubber plastic	Naval Station Key West, Fla.	Plastic drains and vents have been recently installed in 500 homes in Capehart quarters. Drains connect to tile sewer line outside the building. Plastic was chosen for economical reasons.	The installation has not had the test of time but similar systems have been used in photo labs for years so there is every reason to believe it will be satisfactory.

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13. ABSTRACT
To determine the effectiveness of methods used in the field to protect pipeline systems from corrosion within a group of government activities, engineers from the U. S. Naval Civil Engineering Laboratory made on-site investigations of piping distribution systems in a total of twenty-three Naval activities located in various places of the Pacific coast, Atlantic coast, gulf coast, Hawaii and inland California. The data collected from the sites were more commonly from service pipelines such as steam, hot water, potable water, sea water, sewage, air, gas and oil. One hundred and six pipe installations were investigated. Information as to site, soil characteristics, type of coating or covering, date of installation, length of pipe involved, and reports on the success or failure of the systems are recorded in tabular form and entered in Appendixes A and B. The most serious failures reported are in underground hot pipeline systems where, in most cases, the lines are installed below the water table.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Protection	8					
Corrosion	8					
Coatings	9					
Pipes	8,9,4					
Pipelines	8,9,4					
Steam Pipelines	8,9,4					
Hot Water Pipelines	8,9,4					
Potable Water Pipelines	8,9,4					
Sea Water Pipelines	8,9,4					
Sewer Pipelines	8,9,4					
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